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CHEMICAL STABILIZERS FOR THE CONTROL OF FUGITIVE ASBESTOS EMISSIONS FROM OPEN SOURCES

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16. ABSTRACT

Quarried serpentinite, recently found to contain asbestos, is used as aggregate for surfacing secondary roads. Emission concentrations of 0.6×10^6 to 8×10^6 fibers/m^3 were collected 20 m downwind from a serpentinite surfaced roadway. These levels are up to 55 times greater than background levels and correspond to emission factors of 34×10^{10} to 370×10^{10} fibers/km-vehicle at a vehicular traffic speed of 13.4 m/sec (30 mph).

Chemical treatments were tested for controlling these asbestos emissions. Laboratory tests were developed for screening fifty-one candidate commercial materials. Four of the most promising were field-tested. Asbestos emission fiber count reductions of 80% to 90% were achieved with chemical treatments at application rates ranging from \$0.08/m^2 to \$0.25/m^2. Comparable emission reductions were demonstrated with traffic speeds reduced from 13.4 m/sec (30 mph) to 6.7 m/sec (15 mph).

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-CI) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

The study described in this report was undertaken to test commercially available dust suppressants to control asbestos emissions from unpaved serpentinite roadways. Crushed serpentinite is used as road aggregate where it is locally plentiful. The application of dust suppressants during warm, dry seasons can minimize the exposure of the local populations near such roadways. The results will be of value to those who construct and maintain unpaved serpentinite roadways. It will also be of value to those who wish to test other dust suppressants for roadway applications. Further information concerning this subject can be obtained by contacting the Nonferrous Metals and Minerals Branch of the Energy Pollution Control Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

Quarried serpentinite, recently found to contain asbestos, is used as aggregate for surfacing secondary roads. Emission concentrations of 0.6 x 10^6 to 8 x 10^6 fibers/m^3 were collected 20m downwind from a serpentinite surfaced roadway. These levels are up to 55 times greater than background levels and correspond to emission factors of 34 x 10^{10} to 370 x 10^{10} fibers/km-vehicle at a vehicular traffic speed of 13.4 m/sec (30 mph).

Chemical treatments were tested for controlling these asbestos emissions. Laboratory tests were developed for screening fifty-one candidate commercial materials. Four of the most promising were field tested. Asbestos emission reductions of 80 to 90% based on fiber count were achieved with the chemical treatments at application rates ranging from \$0.08/m^2 to \$0.25/m^2 (1979). Comparable emission reductions were demonstrated at a traffic speed reduced to 6.7 m/sec (15 mph).

This report is submitted in fulfillment of Cooperative Agreement No. R-806269 by IIT Research Institute under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers the period from October 1, 1978 to December 31, 1980, when the work was completed.

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We also owe thanks to Mr. Tom Nemo and Mr. Jack Davis for permission to use their fields to mount our field sampling stations, and to Mr. Davis for rearranging his harvesting schedule to accomodate us.

Mary K. Stinson understood the need for the program and nurtured it into existence. It was largely through her efforts and the efforts of Mr. Gilbert Wood, of the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, that the field test site was located and selected.

IITRI staff members who contributed to the program, which was administered out of Fine Particles Research Section, include: John D. Stockham, Manager of Fine Particles Research Section; Paul K. Ase, Principal Investigator; Roger Koch, who developed the laboratory tests; George Yamate, who conducted the electron microscope analysis; Dr. Renny Norman, who advised us in the design and construction of the wind tunnel; and Dennis Finn, Richard Jambor, and Donald Krystof, who ably conducted the laboratory and field tests.

SECTION 1

INTRODUCTION

The health hazards associated with the manufacture and commercial use of asbestos are well documented. As a result of its concern with these hazards, the U.S. Environmental Protection Agency is seeking methods for reducing public exposure to asbestos from identified emission sources. The present study was conducted to assess control of asbestos emissions from crushed serpentinite rock on unpaved roadways with chemical control agents. Laboratory screening tests were developed to select promising agents. Application rates were selected based on material costs. Then field tests were conducted on the four materials which showed greatest promise in the laboratory tests.

Quarried serpentinite crushed stone is the major source of crushed stone where it is readily available and in localities where access to limestone is limited. Limestone is preferred since it is a sedimentary material, and therefor has better weathering properties. Serpentinite is used as road aggregate material for parking lots, driveways, and on country roads. It is also used as a base course for highways, concrete aggregate, and binder filler for asphalt paving. Serpentinite rock formations occur at or near the earth's surface in many regions of eastern United States. Belts of serpentinite extend from Maine to Alabama, covering much of the Appalachian Mountains (L.J. Carter, 1977). Serpentinite is also native to extensive regions of the western United States, from the state of Washington to California.

The bulk of serpentinite quarried in the United States for crushed stone is made up of antigorite. However, chrysotile, tremolite, deweylite, talc, anthophyllite, and other silicate minerals have been reported to occur in serpentinite (D.M. Larrabee, 1969; A.N. Rohl, A.M. Langer, and I.J. Selikoff, 1977). Dustfall collected along roads and trails in a western recreational area located over a serpentinite massif was found to contain 90% chrysotile (W.C. Cooper, et al, 1979). The asbestos in crushed stone from serpentinite quarries have been analyzed recently (D.R. Jones, 1980) for the EPA. The

average asbestos concentrations range from 10×10^{10} fibers/g to 100×10^{10} fibers/g, representing roughly 0.1% to 1.% by weight asbestos in the quarried stone.

Wind erosion created the "dust bowl" and devastated the Great Plains nearly fifty years ago. The study of soil erosion and soil suspension mechanisms since that time has provided us with much of our present understanding of the mechanism of dust generation by the wind's "action" near the earth's surface (W.S. Chepil, 1945; N.C. Woodruff and F.H. Siddoway, 1965; D.R. Dunbar, et al, 1974). Aerodynamic forces, mechanical forces and forces holding particles in the ground are involved in active linkage in soil erosion when the wind is the main active agent involved.

The extent of the loss of particles from a surface is a function of both the particle size and the wind velocity at the surface. Basically, three mechanisms are involved: saltation, surface creep, and suspension. Saltation occurs with particles in the range of 0.05 mm to 0.5 mm. These particles are large enough to protrude into the air stream at the ground surface but small enough to be picked up and bounced along the surface. These particles are imparted with a spinning, leaping action which dislodge other particles, both larger and smaller. Surface creep is effective for particles in the 0.5 mm to 1.0 mm size range. Here the particles tend to creep over the surface exposing other particles and fresh surface to erosion forces. They do not ordinarily become airborne themselves. The smallest particles, less than 0.1 mm in diameter, are too small to be directly picked up by the air currents, but they are readily launched by impact from the larger saltation particles. It is these smallest particles which are suspended and carried off in the wind stream (W.S. Chepil, 1945).

The erosive action of vehicular passage is much more severe than that by wind alone. The large dust plume in the wake of an automobile on a dirt road gives visible demonstration to the intense dust generating forces that accompany vehicular traffic on unpaved roadways. The mechanical action of the tires on the road surface kicks up dust particles and places them into direct suspension. The simultaneous turbulence of vehicular movement adds more suspension in the wake. Large dust plumes are formed which are easily dispersed by the faintest air currents.

On unpaved crushed stone roadways, the pressure of vehicular tires on the road surface applies high sheer forces on the unbound rock which replenishes the fines lost to suspension by intense grinding action. The effect of vehicular traffic on surface aggregates is much more severe than the action of wind alone, and the amount of stabilizer material needed to control roadway emissions is consequently much greater than that required to control emissions from surfaces not subjected to active mechanical disturbances.

The present program was undertaken to determine the extent to which dust control agents might provide control over asbestos emissions from the use of crushed serpentinite rock on unpaved roadways. Laboratory tests were developed to screen control agents and levels of their application. In all, sixty-nine materials were considered. Of these, fifty-one were screened in these laboratory tests. Three levels of application, based on cost of control agents, were tested. Then field tests were conducted with four of the most promising materials. Transmission electron microscope (TEM) analysis of air samples collected near the roadway were used to evaluate the effectiveness of control agents in field applications.

SECTION 2

CONCLUSIONS

Serpentinite is native to many parts of eastern and western United States. Serpentinite rock in some of these regions is quarried and is used locally as aggregate for surfacing material on secondary roads. Quarried serpentinite is known to contain asbestos.

Chemical stabilizers were tested for controlling asbestos emissions from unpaved roadways surfaced with crushed serpentinite. Readily measurable asbestos emission over background levels were collected from the untreated roadway. Emission factors of 34×10^{10} to 370×10^{10} fibers/km-vehicle were reached at vehicular traffic speeds of 13.4 m/sec (30 mph). These emission generation levels correspond to ambient concentrations of 0.6×10^{6} to 8×10^{6} f/m^3 collected 20 m downwind from the road. Fiber count concentrations were reduced by 80-90% with chemical treatment. Similar reductions were achieved with reduction in traffic speed to 6.7 m/sec (15 mph).

The asbestos emissions, with fiber density of 50,000 fibers/ng, were essentially all chrysotile asbestos. The observed fibers were all in the respirable range and averaged <0.1 μm in diameter and <2 μm in length. The emission fibers were classified in terms of four structural forms: individual fibers, matrices, bundles, and clusters. The fiber structure in the roadway emissions were mostly either single fibers or fibers attached to rock matrix material. Very few bundles or clusters of fibers were found. The fiber structures in the emission from the untreated roadway section and the treated roadway sections were indistinguishable.

Respirable emission levels were much lower than expected from the concentration of asbestos fibers in the dust from fresh quarry crushed aggregates. This may be due, in part, to the manner in which the serpentinite tends to break up along asbestos-containing seams during crushing. It may also be due, in part, to the occurrance of larger aggregates in which the fibers are still bound and not released.

Two types of chemical stabiliziers for asbestos emission control were identified:

(1) Stabilizers which form a solid, water-resistant surface coating and bind road aggregates together--After 6 months they still retained better than 80% emission reduction when applied at the level of $\$0.20/m^2$ to $\$0.25/m^2$ (1979).

(2) Stabilizers which form a water-soluble surface matrix which bind surface particles together--This type may not control aggregate wear as well as the first, but is able to rewet new particulates and repair worn surfaces to minimize emission. These showed little emission control after 6 months when applied at the rate of $\$0.08/m^2$ (1979), but periodic reapplication can be used to maintain emission control.

The treatment choice would depend on a number of factors, including availability of treatment, equipment on hand, and local climatic conditions.

SECTION 3

RECOMMENDATIONS

The four field tested treatments showed that they were capable of controlling asbestos emissions. All four--SS-1H (emulsion oil), Coherox (oil refining byproduct), Liquidow (calcium chloride), and Orzan GL-50 (lignosulfonate)--are recommended for use on serpentinite roadways. The treatment of choice may depend on a number of factors including availability of treatment, equipment on hand, and local climatic conditions.

Control of traffic speed may also provide emission control especially in very dry weather when emissions are greatest.

Emission reductions might also be possible by removing the fines in crushed aggregates either by sieving or by washing out the fibers which concentrate in the initial fines.

To screen a large number of treatments, a simple laboratory test was used. More extensive laboratory tests are recommended to develop application strategies. These should be tailored to take into consideration the physical attributes of the individual treatments.

Even when vehicular traffic is not present, emissions can be generated by the action of the wind alone. These emissions are generated at lower intensity levels from such sources as storage or waste disposal piles. Their treatments can be effective with much lower application rates. They should be subjected to environmental stresses in the laboratory to determine cost effective application rates for control of potentially hazardous emissions from such sources.

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SECTION 4

DISCUSSION OF LABORATORY TESTS

STABILIZER SELECTION FOR SCREENING

There is no data on the comparative effectiveness of stabilizers for the present application, i.e., to control emission of asbestos from crushed stone roadways. Stabilizers were selected from those which showed promise in other applications such as soil stabilizers (Armbrust and Dickenson, 1971; Dean and Haven, 1972), as palliatives for treatment of unpaved roadways (Hoover, 1973; Sultan, 1976), and for application on asbestos waste piles (Harwood and Ase, 1977), as well as other more recent commercial materials. Representative chemical agents which were selected for laboratory screening tests are given in Table 1. Of sixty-nine chemical agents originally selected, fifty-one were tested in the laboratory.

A number of properties for chemical agents are needed for them to act as effective stabilizers. These are listed in Table 2. In addition, for roadway use it would be useful for the chemical agents to have a regenerative capacity in order to maintain control action in spite of the continual generation of fresh particulates from the pulverization of surface materials.

The stabilizer cost was used as a basis for comparing stabilizer effectiveness in the laboratory tests. Application rates of \$0.01/m^2, \$0.05/m^2, and \$0.25/m^2 were selected. These rates are based on the bulk material prices shown in Table 1. The amount of each material corresponding to an application rate of \$0.25/m^2 required for a 1 m^2 x 2.54 cm (1 in.) deep application is shown in the last column of the same table.

LABORATORY TEST PROCEDURES

In the laboratory screening tests, the main emphasis was placed on the measurements of treatment control effectiveness. Ball milling was selected

TABLE 1. STABILIZERS FOR SERPENTINITE ROADWAY APPLICATION

IITRI No.	Stabilizer Name	Chemical Type	Manufacturer	Stabilizer Cost, $/lb	Application Rate for $0.25/m^2, Kg/m^2*
1	Epoxy Resin 410	Epoxy Resin	Thermoset Plastics	1.41	0.080
2	Polyco 2445	Styrene butadiene copolymer	Borden Chemical Co.	0.50	0.226
3	Polyco 2607	Vinyl chloride based latex	Borden Chemical Co.	0.59	0.2607
4	E801 Corn Steepwater	Sugar and protein solution wet milling steepwater	Corn Products		S
5	Soiltex	Lignosulfonate	Protex Industries		S
6	Geon 652	Latex	B.F. Goodrich	0.625	0.181S
7	Goodrite 2570X1	Latex	B.F. Goodrich	0.59	0.192
8	Norlig A	Calcium lignosulfonate	American Can Co.	0.0775	1.460
9	M167		Dow Chem. Dowell Div.	0.365	0.311
10	M186		Dow Chem. Dowell Div.	0.145	0.782
11	M166		Dow Chem. Dowell Div.	0.345	0.329
12	Soilguard	"Rubbery" latex emulsion	Alco	0.35	0.324
13	DLR-MS	Acrylic Resin	Rohm and Haas	0.13	0.872
14	Suferm	Sulfur and petroleum products	Chevron	0.127	0.893
15	CR-79R-5023	Similar to Suferm	Chevron	0.127	0.893
16	Latex 153	Organic polymer	Union Carbide		S
17	AC-19	Acrylic Polymer	Rohm and Haas		S

* Based on application to 2.54 cm (1 inch) depth for material costs May, June 1979.
S = Scratched.

TABLE 1. (Continued)

IITRI No.	Stabilizer Name	Chemical Type	Manufacturer	Stabilizer Cost, $/lb	Application Rate for $0.25/m^2, Kg/m^2*
18	8800	Wetting agent	Nalco	0.512	0.221
19	8820	Organic Binding agent	Nalco	0.577	0.197
20	Paraplex	Arcylic resin	Rohm and Haas		S
21	Vinsol Emulsion	Resin emulsion	Hercules	0.146	0.777
22	Neuphor 100		Hercules		S
23	Purocol 404C	Paraffin wax emulsion	Hercules	0.25	0.454
24	Abitol AXK 257	High molecular wt alcohol plasticizer	Hercules	0.80	0.142S
25	Abitol ATK 9	High molecular wt alcohol plasticizer	Hercules		S
26	Piccolyte D100	Petroleum resin	Hercules	0.45	0.252
27	Reten 304		Hercules	0.476	0.238
28	Defloc 50	Cationic polymer - flocculant	Hercules	0.171	0.663
29	Kymene 557-H		Hercules	0.169	0.671
30	Polyrod 1110A	Ethoxylated amine	Hercules	0.79	0.144
31	Amine D Acetate 70%	Amine acetate solution	Hercules	0.82	0.138
32	Rezosol 5411-13	Organic polymer adhesive	E.F. Houghton	0.53	0.214
33	Ethomeen T112	Ethoxylated aliphatic amine	Armak	0.80	0.142
34	Arquad 2HT-75	Quaternary ammonium compound	Armak	0.69	0.164S

* Based on application to 2.54 cm (1 inch) depth for material costs May, June 1979.
S = Scratched.

TABLE 1. (Continued)

IITRI No.	Stabilizer Name	Chemical Type	Manufacturer	Stabilizer Cost, $/lb	Application Rate for $0.25/m^2, Kg/m^2*
35	Arquad 2C-75	Quaternary ammonium compound	Armak	1.16	0.098S
36	Mixed Crude Amine	Surfactant - amine	Armak	0.55	0.206
37	Petron DC-6	Acrylic resin	Apollo	0.41	0.277
38	Petron DC-4	Acrylic resin	Apollo	0.46	0.247
39	Petron DC-5	Acrylic resin	Apollo	0.35	0.324
40	Petron DC-7	Wetting agent	Apollo	0.80	0.142
41	Liquidow	Calcium chloride (soln.)	Dow Chemical Co.	0.0151	7.498
42	Curosol AK	Propietary copolymer soln.	American HOECHST	0.48	0.236
43	Gelvatol 20-60	Partially hydrolyzed polyvinyl alcohol	Monsanto	0.905	0.125
44	Tech. Prot. Coll. 2236	Protein	Swift Company	0.56	0.203
45	Tech. Prot. Coll. 2260	Protein	Swift Company	0.60	0.189
46	Tech. Prot. Coll. 5V	Protein	Swift Company	0.80	0.142
47	Tech. Prot. Coll. IV	Protein	Swift Company	0.78	0.145
48	Corexit 170	Surfactant	Exxon	0.48	0.236

* Based on application to 2.54 cm (1 inch) depth for material costs May, June 1979.
S = Scratched.

TABLE 1. (Continued)

IITRI No.	Stabilizer Name	Chemical Type	Manufacturer	Stabilizer Cost, $/lb	Application Rate for $0.25/m^2, Kg/m^2*
49	Polymethylhydro-siloxane	Water repellant	Alpha Chemical		S
50	Lamitex SF120		Multi Kem Corp.		S
51	Protatek EFN	Sodium alginate	Multi Kem Corp.		S
52	MC-30	Cut-back asphalt	Ashland Oil	0.087	1.300
53	Norlig NG	Ammonium lignosulfonate	American Can Co.	0.10	1.134
54	Marasperse N-22	Sodium lignosulfonate	American Can Co.	0.14	0.810
55	Foramine 21-194	Urea formaldehyde resin	Reichhold Chem.		S
56	UCAR Latex 153	Copolymer	Union Carbide		S
57	Rhoplex AC-19	Acrylic Polymer	Rohm and Haas	0.245	0.463
58	Sodium Silicate #9	Inorganic chemical	DuPont	0.04	2.835
59	Coherex	Petroleum resin - H_2O Emulsion	Witco	0.0603	1.880
60	SP-400	Organic polymer - adhesive	Johnson-March		S
61	Elvanol	Polyvinyl alcohol (fully hydrolyzed)	DuPont	0.72	0.158
62	Aerosol GPG	Surfactant	American Cyanamid	0.40	0.284
63	Superfloc 16	Flocculant	American Cyanamid		S

* Based on application to 2.54 cm (1 inch) depth for material costs May, June 1979.
S = Scratched.

TABLE 1. (Continued)

IITRI No.	Stabilizer Name	Chemical Type	Manufacturer	Stabilizer Cost, $/lb	Application Rate for $0.25/m^2, Kg/m^2*
64	Aerospray 70	Polyvinyl acetate emulsion resin	American Cyanamid	0.44	0.258
65	Orzan GL-50	Ammonium lignosulfonate	Crown Zellerbach	0.015	7.560
66	Water (control)	Water			(6.119)†
67	Dust Oil	Cut-back asphalt petroleum product	Douglas Oil	0.046	2.465
68	SS-1H	Asphalt emulsion in water	Douglas Oil	0.046	2.465
69	SC-70	Cut-back asphalt petroleum product	Douglas Oil	0.054	2.100

* Based on application to 2.54 cm (1 inch) depth for material costs May, June 1979.
S = Scratched

† Based on 50 ml for 10.2 cm diam. in lab test application.

TABLE 2. DESIRABLE PROPERTIES OF STABILIZERS

Low Application Cost
Water Soluble
High Bondability to the Particles Under Consideration
Long Life and Stability
Resistant to Heat and Cold
Nonphytotoxic
Biodegradable
No Water Pollution Problems from Drainage Water
Easy to Clean from Application Devices
Effective in Low Dilutions

to simulate the wear action of vehicular traffic over crushed stone road beds. The fraction of fines, measured by sieve analysis, was used to determine stabilizer effectiveness. The overall laboratory test procedure used a series of six consecutive steps. Preliminary tests were conducted to identify and quantify the important parameters in each step. These were carefully examined to ascertain the compatibility of the various steps in the procedure.

The following steps were followed:

1. Sample Preparation--Weighing and Drying
2. Initial Sieve Analysis
3. Treatment Application
4. Rain Cycling
5. Traffic Simulation
6. Final Sieve Analysis

All of the above steps were followed in the rain cycled screening tests; however, step 4 was omitted for the dry cycled tests; and water was used in step 3 for the characterization of the control (water) samples.

Preliminary tests were conducted to develop procedures for generating fines in a reproducible manner in a reasonable short time period. The laboratory tests were performed on crushed serpentinite rock which was donated to us by Rockville Crushed Stone, Inc., Rockville, Maryland. In order to be assured of an adequate amount of fines, " 3/8 inch crushed stone" was substituted for the " 1½ inch crushed stone" which is generally used for roadway surface application. While only 1.5 wt % of the latter is <140 mesh, nearly 9.0 wt % of the former was found to make up the <140 mesh fraction. This gave us a larger proportion of fines to work with in each sample. Ball milling conditions were selected to increase by 50% the <140 mesh (0.105 mm openings) weight fraction of the untreated crushed stone. These same test conditions were incorporated into the traffic simulation procedure for all the treated samples.

Sample Preparation

A sample weight of 300 g was selected for the laboratory screening tests. The samples were dried overnight (12 hours) at 60°C (140°F) in an environmental chamber. Total sample dry weights were measured to the nearest 0.1 g.

Each gravel sample was placed in a sample holder consisting of a 3.8 cm (1.5 inches) tall segment of 10.2 cm (4 inches) diameter PVC pipe, glued with PVC pipe cement to a 12.7 cm (5 inches) square piece of 30 mesh steel screen. This sample holder was lined with a 20.4 cm (8 inches) square piece of polyester lining fabric. The cloth liner retained the loose fines in the sample holder. The test chemical solution was applied and thoroughly mixed into the gravel sample with a steel spatula. The sample surface was leveled with the spatula and each sample was then dried for 12 hours in the environmental chamber at 60°C (140°F).

Rain Cycle

Next, each treated sample was subjected to 6.7 cm (2.6 inches) ± 1.7 cm (0.7 inches) of total rainfall at the rate of 13.3 cm/hr (5.2 inches/hr). After the rain cycle, each sample was redried overnight (12 hrs) at 60°C (140°F) in the environmental chamber in preparation for the next step.

The rain chamber was designed to apply a controlled simulated rain to a large number (32) of samples, simultaneously. An array of eight nozzles (Spraying Systems, Type TG-1) located 2.1 m (7 ft) above the sample positions is used. The nozzle flow is controlled with a single upstream pressure regulator maintained at 12 psi. Simulated rain drops ∿1.2 mm in diameter are formed. This drop size is typical for a moderate to intense rain. The nozzle precipitation patterns are overlapped. The resulting precipitation rate has a site to site variability of 25% as measured by the standard deviation.

Traffic Simulation

Traffic abrasion on the treated samples was simulated with a ball mill. Each sample (300 g) is placed in a 1.1 liter (40 oz) ball mill jar containing 550 g of 1.91 cm (0.75 inches) diameter ceramic balls and ball milled for 1.0 minute using an automatic timer to control the duration. A ball mill rotational velocity of 70 RPM with a 12 cm (4.7 inches) diameter ball mill was used. The results in terms of the weight fraction of fines <140 mesh were fairly consistent (S = ±10%) and the same ball milling conditions were used for all samples subjected to the traffic simulation test.

Final Sieve Analysis

After all of the tests were performed on the crushed stone samples, they were screened according to the same procedures used in the initial sieve analysis tests. Then the "final weight % <140 mesh" was determined for each sample.

LABORATORY TEST RESULTS

The treatment effectiveness of each stabilizer treatment was calculated as the weight fraction of fines <140 mesh found in each sample after the traffic simulation compared to the weight fraction of fines <140 mesh found initially in each sample. The treatment effectiveness is referred to here as the Treatment Score, TS:

$$TS = \frac{\text{Final Wt \% <140 mesh}}{\text{Initial Wt \% <140 mesh}}$$

where the Wt % is based on the total dry sample weight. The treatment effectiveness, TS (treatment), is further normalized by comparison with the treatment effectiveness of the control, TS (control), treated with water only. The value for the normalized treatment effectiveness is referred to as Relative Treatment Score, RTS:

$$RTS = \frac{TS\ (treatment)}{TS\ (control)}$$

The RTS is the ratio of the treatment effectiveness for a particular stabilizer at a selected treatment level (e.g., $\$0.01/m^2$, $\$0.25/m^2$) compared to the effectiveness with only water (control). The value for TS (control) was calculated from the average of randomly selected control samples. The average Treatment Score, TS (treatment), for all the samples at the $\$0.01/m^2$ level are compared with TS (control) for the five control samples in Table 3. The coefficients of variation show good agreement while the agreement between the average TS values indicates that the stabilizer applications at the $\$0.01/m^2$ concentration are ineffective for road traffic emission control.

TABLE 3. COMPARISON OF AVERAGE TREATMENT SCORES, TS (TREATMENT), AT THE $0.01/m^2$ APPLICATION LEVEL WITH TS (CONTROL)

	TS (Control)	TS (Treatment)
Average, ($\bar{x}$)	1.41	1.44
Standard Denotations, (S)	0.14	0.16
Coefficient of Variation, ($S/\bar{x}$)	0.10	0.11

As an aid in ranking treatments for RTS values, Treatment Effectiveness Ranks (TER) were defined. They were defined so that the most effective treatments could be easily distinguished from the rest. The control effectiveness in decreasing order of effectiveness is $5 > 4 > 3 > 2 > 1 > 0$. They were grouped as follows:

Relative Treatment Effectiveness Rank (RTER)	Relative Treatment Score (RTS)
5	$0.00 \leq RTS \leq 0.01$
4	$0.01 \leq RTS \leq 0.10$
3	$0.10 \leq RTS \leq 0.25$
2	$0.25 \leq RTS \leq 0.50$
1	$0.50 \leq RTS \leq 0.75$
0	$0.75 \leq RTS$

The results of the laboratory screening tests are given in Table 4. Seven of the most promising stabilizer treatments in the laboratory tests are shown in Table 5. They each gave high RTER ranks at the $0.25/m^2$ level of treatment application. Of these, Liquidow, Orzan GL-50, Coherex, and SS-1H were selected for field testing. The first two are water soluble and therefore have some regenerative capacity which is activated when wet. On the other hand frequent heavy precipitation will cause them to rapidly dissolve away. Thus they are best applied with periodic replenishment. The other two are applied as water-based emulsions but once applied they do not rewet new surfaces. The other materials in Table 5 are cut-back oils and their use is discouraged by the EPA because they contain large fractions of volatile hydrocarbons.

TABLE 4. LABORATORY SCREENING OF STABILIZERS FOR UNPAVED ROADWAYS

IITRI No.	Stabilizer Name	Relative Treatment Scores (RTS) for Selected Application Rates					Treatment Effectiveness Rank (TER)	
		Without Rain (A)		With Rain (B)				
		$0.05/m²	$0.25/m²	$0.001/m²	$0.05/m²	$0.25/m²	Without Rain (A)	With Rain (B)
1	Epoxy Resin 410	--	1.08	1.08	1.04	1.11	0	0
2	Polyco 2445	0.88	0.48	0.99	0.87	0.21	2	3
3	Polyco 2607	0.78	0.54	1.05	0.85	0.62	1	1
7	Goodrite 257-0X1	0.80	0.56	1.13	0.86	0.66	1	1
8	Norlig A	1.00	0.51	1.10	1.16	0.74	1	1
9	M167	0.81	0.47	1.09	1.10	0.48	2	2
10	M186	--	0.72	1.15	0.90	0.88	1	0
11	M166	0.75	0.32	0.98	0.94	0.45	2	2
12	Soilguard	0.89	0.49	1.10	0.83	0.48	2	2
13	DLR-MS	0.75	0.26	1.00	0.77	0.27	2	2
14	Suferm	0.99	0.54	0.86	0.95	0.63	1	1
15	CR-79R-5023	--	1.02	1.12	1.10	0.96	0	0
18	8800	--	1.04	1.06	1.03	0.87	0	0
19	8820	--	0.96	1.02	1.12	0.84	0	0
21	Vinsol Emulsion	--	0.94	0.94	1.16	1.00	0	0
23	Purocol 404C	--	1.26	0.94	0.93	0.89	0	0
26	Piccolyte D100	--	--	0.78	1.06	1.46	-	0
27	Reten 304	--	0.89	1.03	1.05	0.82	0	0
28	Defloc 50	--	1.02	0.85	1.09	1.25	0	0
29	Kymene 557-H	--	0.89	1.04	0.98	0.87	0	0
30	Polyrad 110A	--	1.10	1.15	1.00	1.05	0	0
31	Amine D Acetate 70%	--	1.06	0.65	0.94	0.97	0	0
32	Rezosol 5411-13	--	1.19	0.98	1.22	0.87	0	0
37	Petron DC-6	--	0.68	1.10	1.13	0.68	1	1

* TER are based on RTS values in laboratory screening tests for $0.25/m² application rate: (A) Without Rain, and (B) With Rain.

TABLE 4. (Continued)

IITRI No.	Stabilizer Name	Relative Treatment Scores (RTS) for Selected Application Rates					Treatment Effectiveness Rank (TER)	
		Without Rain (A)		With Rain (B)			Without Rain (A)	With Rain (B)
		$0.05/m²	$0.25/m²	$0.001/m²	$0.05/m²	$0.25/m²		
38	Petron DC-4	0.71	0.50	0.88	0.95	0.40	2	2
39	Petron DC-5	--	0.91	0.89	1.15	1.09	0	0
40	Petron DC-7	--	1.05	0.94	1.00	0.85	0	0
41	Liquidow	0.55	0.00	1.05	0.76	0.00	5	5
42	Curosol AK	--	0.77	0.93	0.84	0.95	0	0
43	Gelvatol 20-60	--	0.56	1.24	0.83	1.04	1	0
44	Tech Prot Coll 2236	--	--	1.03	1.12	1.02	-	0
45	Tech Prot Coll 2260	--	--	1.11	0.90	0.89	-	0
46	Tech Prot Coll 5V	--	--	--	1.02	1.11	-	0
47	Tech Prot Coll 1V	--	--	--	1.02	0.88	-	0
48	Corexit 170	--	0.99	0.91	0.88	0.74	0	1
52	MC-30	1.00	0.00	0.98	0.89	0.11	5	3
53	Norlig NH	--	0.74	1.14	0.94	0.78	1	0
54	Marasperse N-22	--	0.74	1.17	1.30	0.89	1	0
57	Rhoplex AC-19	0.69	0.27	1.05	0.98	0.38	2	2
58	Sodium Silicate #9	0.97	0.45	1.10	1.00	0.39	2	2
59	Coherex	0.99	0.01	1.04	1.14	0.11	5	3
61	Elvanol 71-30G	--	0.83	1.13	1.07	1.12	0	0
62	Aerosol GPG	--	0.72	0.94	0.70	0.92	1	0
64	Aerospray 70	0.92	0.42	1.03	0.90	0.87	2	0
65	Orzan GL-50	0.55	0.00	0.89	0.75	0.00	5	5
67	Dust Oil	0.84	0.00	--	0.65	0.00	5	5
68	SS-1H	0.87	0.05	--	0.91	0.00	4	5
69	SC-70	0.88	0.02	--	0.81	0.02	4	4

* TER are based on RTS values in laboratory screening tests for $0.25/m² application rate: (A) Without Rain, and (B) With Rain.

TABLE 5. MOST PROMISING STABILIZERS IN LABORATORY TESTS

IITRI S/N	Stabilizer Name	Type	Treatment Effectiveness Rank (TER)	Application Rate for $0.25/m^2*	
				$1/m^2$	gal/yd^2
41	Liquidow	Calcium Chloride aq. solution	5	7.2	1.6
52	MC-30	Cut-back asphalt	3	1.3	0.29
59	Coherex	Petroleum resin emulsion	3	1.8	0.40
65	Orzan GL-50	Ammonium ligno-sulfonate	5	7.2	1.6
67	Dust oil	Cut-back asphalt	5	2.5	0.53
68	SS-1H	Asphalt emulsion	5	2.5	0.53
69	SC-70	Cut-back asphalt	4	2.1	0.46

* Based on application depth of 2.54 cm (1 inch).

SECTION 5

DISCUSSION OF FIELD TEST PROGRAM

Four of the most highly ranked laboratory treatments were selected for field testing (see Table 5). These treatments were applied on the roadway. Then upwind and downwind sampling stations were set up and initial samples were collected one week after application. A visual inspection of the road site was made six weeks after application and then a second series of traffic emissions tests were conducted about 6 months after the initial sampling tests. The high volume filter samples were hand carried back to our laboratory in Chicago, and samples were analyzed by transmission electron microscope (TEM) methods for ambient air asbestos (Samudra, Harwood, and Stockham, 1978).

In these field tests we have attempted to determine the fiber emissions reductions for treatment application which were highly favored in laboratory tests. There are many field variables which may be tested and samples which might be collected but as in other field tests, it has been necessary to drastically limit the variables under examination. The analysis for asbestos fiber was limited to transmission electron microscope (TEM) analysis. The TEM procedures for ambient air asbestos analysis are time consuming and expensive, but they give the most direct information on the concentration of asbestos in the ambient air and show the effectiveness of treatments most directly. Although many more field samples were collected, only a limited number were selected for actual TEM analyses at this time. Selections were limited to those collected under the most favorable meteorological conditions for sampling.

FIELD TEST SITE

Test Site Selection

Initially, a test site was sought in the area where serpentinite asbestos emissions were originally reported (Rohl, Langer and Selikoff, 1977). However, in the Rockville area all of the public roads surface with crushed serpentinite stone were already paved over. An area in Northern Maryland was located where serpentinite was still in use on secondary unpaved roadways. A suitable

roadway was found north of Hickory in Harford County, Maryland. The county was very cooperative. The road site was remote and local acceptance of our field operations was very good.

The road, which runs almost directly east and west, was suggested to us by the Emission Standard and Engineering Division, Office of Air Quality, Planning and Standards (ESED/OAOPS) (Wood, 1979). The road was used by ESED as part of its assessment of the need for a Federal asbestos standard. Then subsequently the road was used by us for emission control treatments in the present study.

The crushed serpentinite rock used on the road is produced at the Cedar Hill Quarry just north of Harford County in Pennsylvania. This aggregate material is used on approximately 60 miles of unpaved secondary roads throughout the county. Fresh crushed serpentinite, crusher Run No. 6 ($\sim$ <7.5 cm) was applied during the summer along a 500 m field test section. The section of the road used by the ESED field team was used by us as the control section and the rest of the test section was used for treatment applications.

The road is straight in the test section and is well-maintained by the county. Although groves of trees dot the area, the land adjacent to the test section of the road was mainly planted in corn with some fields of wheat and some fields of grass (hay). An unusually wet year delayed the scheduling of initial field experiments for late summer to mid-fall.

Terrain Along the Test Road

Originally it was believed that emission samples should be collected along the road before treatment to establish a base-line emission level. However, the drastically changing terrain patterns were confronted in the fall as road test preparation were being made. Corn was being harvested field by field as weather permitted. We elected to go ahead and treat the road and then conduct emissions testing after harvesting was completed. With this approach, it was possible to select sampling sites on cleared fields. In the spring, the field tests were conducted in fields of young corn which were still only 30 cm (1 ft.) high.

ROAD TREATMENTS

Road dust emissions are, in general, a warm weather problem, but may not be entirely absent during cooler, dry periods of the year. Large thick dust

plumes are possible when the weather is continuously warm and roads dry off quickly. During the cooler months, the dust emissions are much reduced even in the dry regions of the country. The saturation vapor pressure is much greater in the summer months and correspondingly, the evaporation rate is much higher during warm periods compared to cooler periods although the relative humidities may be nearly the same.

Liquidow (Calcium Chloride)

The relative humidity goes through daily cycles. The lower temperatures at night favor high relative humidities while during the day the temperature rises and the same total moisture content in the air may represent a much lower relative humidity. Condensation is greatest in the early morning hours when the relative humidity is highest and the air near the ground is very still.

Deliquescent materials such as calcium chloride and sodium chloride have been used sucessfully to take advantage of these diurnal humidity changes. Deliquescent materials act as reservoirs to capture and retain the moisture in the surface of the road. Sodium chloride becomes deliquescent at a relative humidity of 70% while calcium chloride is active at a relative humidity of 29%. Thus, only the latter is suited for use in the arid regions of the county where relative humidity rarely gets up to 70%.

High precipitation levels deplete the road of the treatment and then periodic reapplications are needed.

Liquidow is a 30% by weight aqueous solution of calcium chloride. Liquidow is manufactured by the Dow Chemical Company. It can be uniformly applied from a tank truck and achieve immediate intimate mixing in the surface of the road. It is much more convenient to apply than the granular material which requires either a light precipitation or vehicular traffic to achieve the intimate mixing needed to get complete dust control.

An application level of 2.7 l/m^2 (0.6 gal/yd^2) is recommended by the manufacturer for dust control of haul roads, then 0.9 l/m^2 (0.2 gal/yd^2) after six months for upkeep.

Orzan GL-50

Lignosulfonates are widely available in the wood pulping industry. Orzan is an ammonium salt of lignosulfate. It is a byproduct of the acid sulfite and alkaline sulfate wood pulping processes and is a product of Crown Zellerbach which is sold as a 50% solution in water. An application rate of 2.7 l/m^2 (0.6 gal/yd^2) is recommended for initial application for dust control of haul roads, then a reapplication of 0.90 l/m^2 (0.2 gal/yd^2) after six months for upkeep.

Coherex

This is a byproduct of the petroleum refining industry produced by the Witco Chemical Corporation. In most applications, Coherex is diluted with water in the ratio 1:4 to 1:10 of Coherex to water. It is an emulsion which is easily diluted and applied. After application, it is difficult to remove. The surface is pliable but firm and not sticky. After a few days the surface is dry and regenerating bonds are not formed. In the present context its behavior is similar to that of SS-1H, although SS-1H appears to form a harder, more brittle matrix coating on aggregates.

SS-1H

SS-1H is a slow setting emulsified asphaltic product which is manufactured to specifications for paving and industrial asphalt defined by the Asphalt Institute (The Asphalt Institute, 1978). It is a hydrocarbon solvent free suspension which is prepared as an emulsion with 60% solids in water. It is applied from an oiling truck on which the temperature is maintained at 38°C to 49°C (100°F to 120°F) during application. A minimum ground surface temperature of >10°C (50°F) is needed. It is recommended for slurry seal treatment and for road mixtures with graded and fine aggregates with a substantial fraction smaller than 2.4 mm in diameter.

ROAD TREATMENT APPLICATION

The field tests were conducted to determine the effectiveness of the most promising laboratory treatments. A section of roadway was prepared for each of the four treatments and a fifth for control with no treatment, as shown in Figure 1.

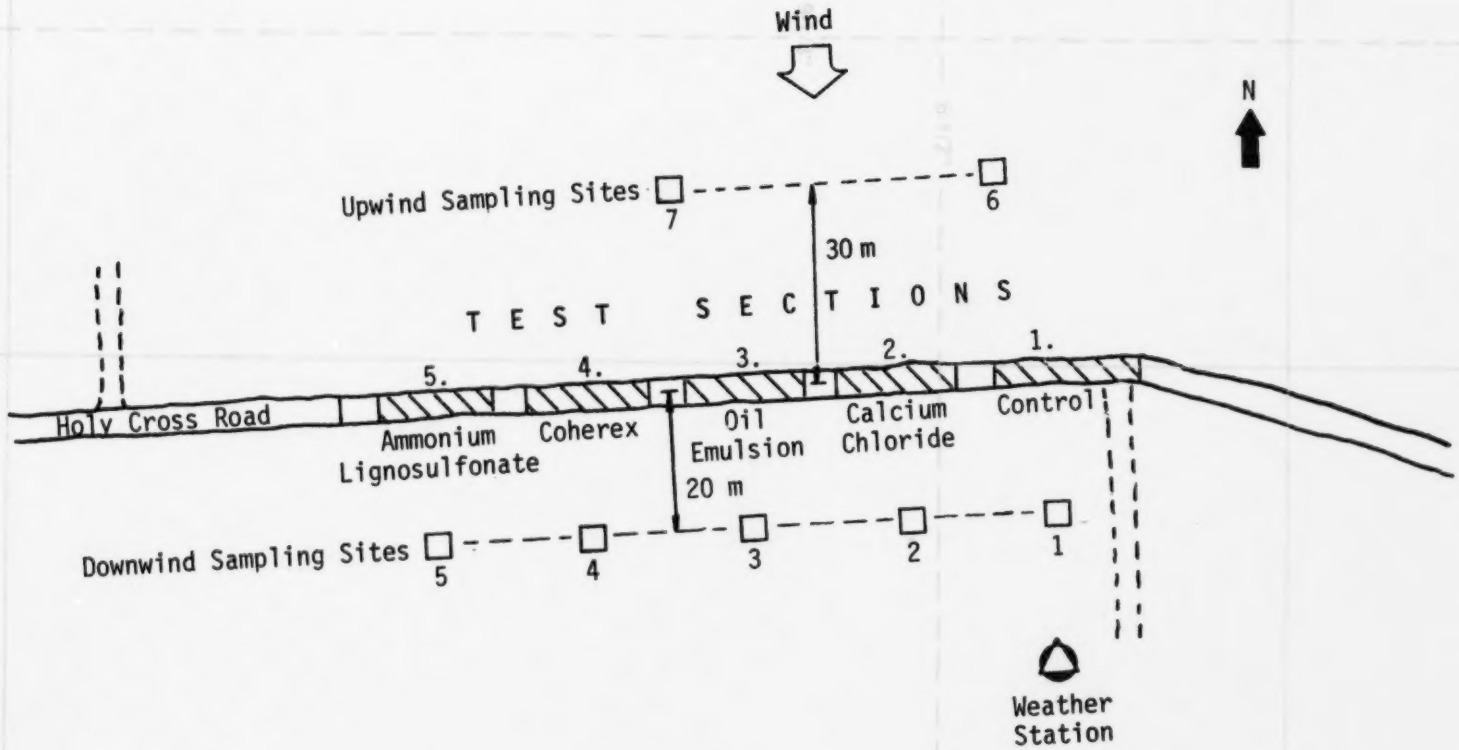

Figure 1. Field Test Sections on Crushed Serpentinite Roadway, Each ∿ 5.5 m x 67.5 m.

To make the treatments accessible to a wide range of potential users, applications were made with readily available road working equipment. A water sprinkler truck and a road grader were used. The equipment and the personnel to run them were made available to our project by the Harford County Highway Department. The grader was used to scrape the road surface to a depth of 2.5 cm (1 inch). This surface loosening operation was done just before treatment application. The treatments and their application rates are shown in Table 6.

TABLE 6. COMPARISON OF LABORATORY AND FIELD APPLICATION RATES

Treatment	Application Rate			
	Laboratory		Field[1]	
	l/m^2	(gal/yd^2)	l/m^2	(gal/yd^2)
Coherex (oil byproduct emulsion)	1.8	(0.4)	1.5	(0.33)
SS-1H (asphalt emulsion)	2.3	(0.5)	2.3	(0.5)
Liquidow (calcium chloride)	7.2	(1.6)	2.3	(0.5)
Orzan GL-50 (lignosulfonate)	7.2	(1.6)	2.3	(0.5)

[1] These treatments were diluted for ease of application and applied at the rate of 4.5 l/m^2 (1 gal/yd^2) of the diluted treatment.

The test sections, each 67.5 m (220 ft) long and 5.6 m (18.5 ft) wide, were separated by 23 m (75 ft) long inhibited sections on which the emulsion oil was applied to minimize "cross talk" between test sections.

All treatments except SS-1H, emulsion oil, were applied from the water truck. All treatments were made in single applications. The amount needed for a 2.5 cm (1 inch) depth was mixed for each test area in the sprinkler truck and applied through a 2.4 m (8 ft) wide sprinkler bar. Between 6 to 10 passes of each treatment were used to get uniform application and to permit the treatment to soak in.

After each treatment application, the grader was used to mix the treatment into surface layer by blading. In this operation the wetted, treated

aggregates were bladed to the center of the road from each side. Then the central pile was spread out and a crown formed in the middle of the road. This procedure was used to provide intimate mixing of the aggregates with the treatment. Several additional passes were then made by the grader to roll out the surface.

In laboratory tests treatment liquid volumes of up to 7.2 l/m² (1.6 gal/yd²) were used. In the field tests treatments were limited to a single application due to time and funds limitations. Initial field tests showed that it was very difficult to get in more than 4.5 l/m² (1 gal/yd²) of liquid at one time. For this reason the total liquid rate was limited to a maximum of 4.5 l/m² (1 gal/yd²). The viscosity of the straight lignosulfonate solution was too high to work with easily from the water truck. Therefore, the solution was diluted 1:1 with water. This made application easier but reduced the amount which could be applied at one time to 2.25 l/m² (0.5 gal/yd.²). To get good penetration of Coherex a 1:2 dilution with water was used. This also affected its application rate and only 82.5% of the laboratory application rate was used in the field. Liquidow application rate was matched with the Orzan GL-50 rate. Both laboratory application rates were the same. An application rate of 2.25 l/m² (0.5 gal/yd.²) of Liquidow was used.

The SS-1H application was maintained at the rate of 2.3 l/m² (0.5 gal/yd²)- same as for the laboratory tests.

Overall the application rate of the two petroleum residue emulsions was kept about the same as for the laboratory applications, while the Liquidow (calcium chloride) and Orzan GL-50 (Ammonium lignosulfonate) application rates were reduced to 1/3 of the laboratory rates. The latter two are similar also in that they dissolve in water and therefore are able to renew bonds with the aggregate particulates. But also frequent precipitation and heavy traffic could decrease the period between reapplications.

The SS-1H oil emulsion was applied by a road contractor. This treatment required a special heated truck which kept the oil heated at near 50°C (120°F) during application from a 3.7 m (12 ft) sprayer bar. The truck was equipped with automatic flow metering to precisely control the application rate. The application was made in five passes over the test section. Application of

SS-1H to the short inhibited sections followed application to the test section. The application was followed by blading and rolling with the grader.

SAMPLING AND ANALYSIS

Roadway Emissions Collection

Upwind/downwind air samples were collected immediately after application of treatments and six months later in the spring. These ambient air samples were collected with high volume samplers on 20.3 cm x 25.4 cm membrane filters. The downwind high volume samplers were located 20 m downwind of the road centerline and aligned laterally with the average wind direction through the middle of each roadway test section. Two upwind stations were located 30 m upwind of the roadway and 150 m apart. High volume sampler flow rates were verified with a pressure drop reading with a 0-7.5 cm Dwyer magnehelic gage, Model 2003 at the beginning and end of each run. The magnehelic gage readings were calibrated with a BGI Universal High Volume Air Sample Calibrator. Meteorological information was obtained continuously from a recording weather station, MRI 1072, which was located in an open field 40 m south of the control section. The instrument gave continuous record of the local wind direction, wind speed and temperature. The instrument readout was used to align the sampling stations to the test sites and the current average wind direction. The average wind direction usually remained fixed throughout a test sampling period. Tests were conducted only when the average wind direction was perpendicular to the roadway. For the duration of the field tests, precipitation data was collected with a Taylor rain gauge, Model 2701, by a local resident near the roadway test section.

Ambient air samples were collected on membrane filters. The bulk of the samples were collected on Nuclepore 0.4 μm pore diameter polycarbonate membrane filters. In addition, Millipore 0.8 μm pore size cellulose mixed ester membrane filters were used to collect emission from the control section in parallel with the polycarbonate filter samplers.

A Whatman 41 cellulose filter was used as a backup support filter for each membrane filter. At the end of a run, each filter was cut up into sections and the sections were placed in separate labeled petri dishes. Each section was placed, face up, on an inverted 150 mm petri dish cover.

The petri dish bottom was placed over the filter section to wedge the filter in place along the periphery. The petri dish was held closed with masking tape and individually stored in self-sealing (ziplock) plastic bags. All of the samples were brought back to the laboratory in the upright position.

The field test sampling conditions for all of the field test runs are given in the Appendix, Table A-1. In all, ten runs were conducted. Test Run 0 was conducted to optimize loading levels. Samples from this test were returned to the IITRI laboratory in Chicago for a quick-look analysis by TEM to estimate the emissions concentration levels collected on the filters, and to optimize vehicular traffic volume and downwind sampling distance for sampling stations. As a result of this initial quick-look determination, main test conditions included 60 passes for traffic volume and 20 m distance from roadway to sampler stations for the rest of the tests. Traffic volume for the tests were generated mainly with paired passes with a standard sized, large sedan and a small van truck. With the exception of Run No. 4, which was conducted at 6.7 m/sec (15 mph), all of the tests were conducted at 13.4 m/sec (30 mph).

Ambient Air Asbestos Analysis

The filter samples were analyzed in accordance with EPA's provisional methodology for ambient air asbestos (Samudra, Harwood and Stockham, 1978). A small wedge of filter was carbon-coated and the particulates transferred from the filter to a 3 mm electron microscope (EM) grid using a modified Jaffe washer technique with chloroform used as the solvent for polycarbonate filters and acetone as the solvent for cellulose mixed ester membrane filters.

The EM grid samples were examined with a JEOL 100C analytical electron microscope in the Transmission Electron Microscope (TEM) mode. Grid samples were screened initially under low magnification by TEM to determine suitability for further examination. In this inspection the grid was examined for loading, uniformity, lack of processing contamination, adequacy of clearing, and damage. Inadequate grids were either reprocessed or discarded and reprepared from another filter section.

Acceptable prepared samples were examined at a 20,000X magnification for chrysotile and amphibole asbestos fibers. Fibers with length to width ratios of greater than 3:1 and substantially parallel sides were recorded. The fibers

were classified as:

- chrysotile asbestos
- amphibole asbestos
- ambiguous (incomplete spot pattern)
- non-asbestos (definitely some other mineral)
- no pattern (unknown, no spot pattern)

Fibers were classified based on morphology and recognition of selected area electron diffraction (SAED) pattern. TEM morphology and SAED patterns from standard samples were used as guides for fiber identification. Fibers showing the tubular structure of chrysotile could be tentatively classified as chrysotile but morphological features alone might not be sufficient to distinguish chrysotile and amphibole from other fibrous minerals. A recognizable SAED pattern is used to confirm identification. Pattern recognition is not always easy for ambient air samples which can include interference from nearby particles and attached aggregates. The ambiguous fibers were not included in the total asbestos count. Thus, the total asbestos count is conservative. Due to the very light fiber loading encountered in the field samples, the procedures for counting at low loading levels were followed. The entire grid opening was scanned and the entire grid opening was considered as a single field. Each grid opening was scanned in a series of parallel scans across the grid until a total of 10 grid openings or 100 total fibers were counted, whichever occurs first. In the roadway emission samples fibers were identified in several contexts with other particulates, not currently considered under the EPA's provisional method for ambient air asbestos.

These have been characterized as asbestos structures (Yamate and Beard, 1980). The deposition pattern in the human respiratory system will be affected by the aerodynamic size of individual structures. The individual "fiber" is considered to be a form of asbestos structure which was isolated from all other particulates. The other structural forms are "bundles", "clusters", and "matrices", by themselves or in combinations. A "bundle" is a single entity composed of fibers in a parallel arrangement with each fiber closer together than one fiber diameter. A "cluster" is a single entity composed of numerous fibers in random orientation with all other fibers intermixed in a single group. A "matrix" is a fiber with one end free and

the other end embedded in some other material. All of these asbestos structures were included as single asbestos entities in the analysis for asbestos fibers, provided they met the test for asbestos by morphology and SAED pattern. Only the asbestos content of a structure was used in determining fiber size, mass, and concentration.

FIELD TEST RESULTS

Suppression of Roadway Emissions

The transmission electron microscope was used as the principal analytical tool for the field test measurements. The results of the TEM analysis are given in Table A-2, A-3 in Appendix A. An example of the TEM asbestos analyis record sheet is shown in Figure 2. The filter loadings were all very light. The asbestos fibers on a count basis are mainly all chrysotile. The amphibole fiber concentration is generally 10%. In Table A-3, asbestos structure distribution for Run 5 and Run 7 are shown. While the rare amphibole is found as a single fiber, chrysotile is about equally found as single fibers and in native rock matrix material. Bundles and clusters are also occasionally observed. The matrix fibers may be characteristic of this asbestiform material which occurs in thin veins in the aggregate serpentinite rock.

The asbestos emissions concentrations from the road were determined as the difference between upwind and downwind concentrations based on the TEM fiber counts. The relevant equations are described in Appendix B. In the control section, the emission factor (f/km-vehicle) varied from 32×10^{10} to 370×10^{10} fibers/km-vehicle ocrresponding to net emission concentrations of 0.6×10^{6} to 7.7×10^{6} fibers/m^2 (see Tables 7-9). The lower levels were collected in mid-fall while the highest levels were collected in the following spring.

Tracer measurements (see Appendix C) in the cleared fields adjacent to the road showed that the vertical plume dispersion from all five test sections was essentially the same at all of the downwind sampling stations. This was used as the basis for making direct comparison between simultaneous measurement of road section emissions.

Sample No._____ Acc. Voltage_____ Date_____

Filter Type_____ Beam Current_____ Grid Box_____

Filter Area_____ Magnification_____ Grid Location_____

Grid Opening Area_____ Comments_____

GO	Struct. #	Struct.	Dimension		SAED Observation					SAED/Image	EDS					ID
			Width	Length	Chyrs	Ampn	Ambig	Non-A	No-P	0°	Na	Mg	Si	Ca	Fe	

TABLE 7. ASBESTOS EMISSIONS FROM TRAFFIC ON TREATED ROADWAY

Test No.	Site No.[1]	Downwind Concentration Of Asbestos Fibers X_T (10^6f/m^3)	Upwind Concentration Of Asbestos Fibers X_B (10^6f/m^3)	Net Asbestos Concentration From Road, X_R (10^6f/m^3)	Asbestos Emission Rate, q (10^6f/m-sec)	Asbestos Emission Factor, E (10^{10}f/km-veh.)
1	1	.625		.579	3.81	34.3
	2	.273		.227	1.49	13.4
	3	.256		.210	1.38	12.4
	4	.146		.100	.66	5.9
	5	.205		.159	1.05	9.4
	6		.044			
	7		.049			
2	1	.940		.813	5.39	32.3
	2	.254		.127	.84	5.0
	3	.282		.155	1.03	6.2
	4	.282		.155	1.03	6.2
	5	.205		.078	.52	3.1
	7		.127			
3	1	1.067		.923	10.18	110.0
	2	.200		.056	.62	6.7
	3	.154		.010	.11	1.2
	4	.099		*	*	*
	5	.141		*	*	*
	6		.166			
	7		.123			
4	1	.186		.112	1.14	13.7
	6		.075			
	7		.074			
5	1	7.80		7.66	62.4	374.
	2	6.23		6.09	49.6	298.
	3	1.20		1.06	8.6	52.
	4	.856		.72	5.9	35.
	5	7.17		7.03	57.3	344.
	6		.141			
7	1	2.021		1.72	9.5	57.
	2	4.87		4.59	25.3	152.
	3	1.081		.78	4.3	26.
	4	.898		.60	3.3	20.
	6		.385			
	7		.221			

[1] Tests and sites not included here were not analyzed by TEM.

* Less than background.

TABLE 8. SUMMARY OF ASBESTOS FIBER GENERATION FROM TRAFFIC ON TREATED AND UNTREATED ROADWAY

Site No.	Treatment	E_A, Roadway Emission Factor during Tests (10^{10} f/km-vehicle) 1	2	3	4[1]	5	7
1	Control - no treatment	34	32	110	14	374	(57)[2]
2	Calcium Chloride	13	5	7	-	298	152
3	Oil Emulsion, SS-1H	12	6	1	-	52	26
4	Coherex	6	6	(5)	-	35	20
5	Lignosulfonate	9	3	(0)	-	344	-
Days following rain (cm)		4(.7)	5(.7)	6(.7)	7(.7)	4(2.1)	2(3.5)
Temperature, °C		14°	13°	18°	19°	25°	22°
Relative Humidity, %		72	80	60	72	54	59

[1]All tests at vehicular speed, U_V, of 805 m/min (30 mph) except for Test 4 for which U_V = 402 m/min (15 mph).

[2]Low

TABLE 9. RATE OF ASBESTOS DUST GENERATION FROM VEHICULAR TRAFFIC ON AN UNPAVED SERPENTINITE ROADWAY--RELATIVE FIBER EMISSION RATES OF TREATED SECTIONS WITH UNTREATED ROADWAY

Site No.	Treatment	Relative Emission Rate					
		1	2	3	4	5	7
1	Control--no treatment	1.00	1.00	1.00[2]	0.12	1.00	0.37[1]
2	Calcium Chloride	0.38	0.16	0.06		0.80	1.00
3	Oil Emulsion, SS-1H	0.35	0.19	0.01		0.14	0.17
4	Coherex	0.18	0.19	(0.04)		0.09	0.13
5	Lignosulfonate	0.26	0.09	(0.00)		0.92	

[1] Normalized to highest for Test 7.

[2] Emission rate for q_V (control) in Test 4 (U_V = 402 m/min) relative to q_V (control) in Test 3 (U_V = 805 m/min).

In Table 8 is given a summary of the asbestos fiber generated by the road traffic. Basically, tests run at 13.4 m/sec (30 mph) are compared with one exception--in Test No. 4 emissions were generated at 6.7 m/sec (15 mph). Tests 1-4 were conducted in mid-fall, one to two weeks after application of treatment. A low emission level is maintained by each of the four freshly applied treatments while the emission rate on the control section increases. Tests 1-3 were conducted four to six days following a 0.7 cm rainfall in mid-fall. Cool days and high relative humidity delayed road surface drying in all test sections. This effect is especially notable in the control section for which emission levels were low.

Runs 5 and 7 show that the calcium chloride and lignosulfonate have been depleted from the road. During the interval of 245 days there were 61 days of precipitation for a total of 566 mm (22.3 inches) of rain and snow. Only 1/3 of the laboratory strength of these two treatments were applied because no more than 4.5 l/m^2 could be absorbed by the aggregates under field test conditions. Repeated applications could have been used to build up the concentration of treatment on the test sections for calcium chloride and lignosulfonate. However, the limit of time did not permit this. The emission factor for the road in Test 5 is almost 4 times greater than the highest rate measured in the fall. The maximum temperature is $5^{o}C$ to $10^{o}C$ higher in the spring and the humidity is lower so that a 2.1 cm rain is readily dried in 4 days and in Test 7, a 3.5 cm rainfall is again drying rapidly so that in 2 days the emission rate is higher than the highest emission rate sampled in the fall. In Test 7, the emissions from the control section appears lower than the level from test section 2 (calcium chloride treatment). The emissions from test section 2 are probably closer to the control section rate than that indicated by the measured results. Overall, the data suggests that the emissions control is very good initially (>90% control) and after six months the control by the oil emulsion and Coherex, both of which are petroleum industry byproducts, is still >80%. The other two have lost their capacity to suppress asbestos emissions in the interval so the drop in effectiveness could be much sooner. But the control could easily be reactivated with additional treatment.

Two types of chemical stabilizers for asbestos emission control were identified:

1) Stabilizers which form a solid, water-resistant surface coating and bind road aggregates together. --This type is represented by SS-1H and Coherex, both of which are petroleum byproducts. After 6 months they still retained better than 80% emission reduction when applied at the level of $\$0.20/m^2$ to $\$0.25/m^2$.

2) Stabilizer which forms a water-soluble surface matrix which binds surface particles together. --This type may not control aggregate wear as well as the first, but is able to rewet new particulates and repair worn surfaces to minimize emission. This type is represented by Liquidow (calcium chloride) and Orzan GL-50 (lignosulfonate). The first is hydroscopic and maintains a high moisture presence in the road surface. The second fills the voids and can be redispersed by wetting or by precipitation. These showed little emission control after 6 months when applied at the rate of $\$0.08/m^2$, but periodic reapplication can be used to maintain emission control.

Concentration of Emitted Respirable Fibers

Essentially all of the asbestos found in the downwind air samples are within the respirable range, i.e., <3.5 μm in aerodynamic diameter. A large fraction of the fibers are still attached to matrix particulates. TEM is not a 3-D instrument and a question might be raised as to whether an association of a fiber and a matrix particle is an artifact of sample collection. Some of the fibers are below and some of the fibers are on top of the matrix particle. Essentially all of those on top of the matrix particle appear to be attached or imbedded rather than merely resting on the particle. This suggests that those fibers which are below the rock have the same kind of association with the non-asbestos materials. This indicates that the fibers in serpentinite, which occur in thin veins and bundles, are in intimate association with the matrix rock but are easily separated into small, thin fibers. These are then emitted.

The concentration of asbestos collected from the control section emissions were much lower than expected from mass emission factor calculations (see B-7). These calculations were based on the measured -200 mesh fraction in the road surface aggregates and the average concentration of asbestos found in bulk quarried crushed stone samples from the Cedar Hill

Quarry (Jones, 1981). Higher asbestos concentrations were reported in the -140 mesh fraction than in the fines released by ball milling the remaining larger aggregates. This suggests that as the stone is crushed at the quarry, the stone tends to fracture along the veins in which the asbestos is concentrated. The asbestos is then readily abraded off from these surfaces.

Several physical factors can account for the higher concentration estimates from analysis of asbestos concentrations in the bulk quarry rock as compared to emissions from the roadway surfaced with the same rock material.

Most of the fugitive particulates ejected from an unpaved road are large particles deposited close to the edge of the road (Sultan, 1976). Fibers embedded in such large matrix particles did not reach the downwind samplers and thus were excluded from EM analysis.

When fresh aggregate is laid on the road, the fiber release may be relatively high. However, the original free fibers may soon be depleted by being emitted into the air or by being washed away. If subsequent grinding of the larger aggregates replaces the original fines with others which contain reduced concentrations of asbestos, the long-term asbestos emissions from the road might be correspondingly reduced.

Those fibers collected on the filters might not be counted if the fibers are locked up with the aggregates. The presence of these fibers would not be evident under EM analysis also.

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APPENDIX A

TABLES

TABLE A-1. FIELD TEST SAMPLING CONDITIONS

Test	Date	Time Initial	Period t (min)	No. of Vehicular Passes Nv	Vehicular Speed m/min (mph)	Temp. (°C)	Rel. Humid. (%)	Latest pptn (cm)	Period Since pptn (days)	Cloud Cover (%)	Windspeed[1] (m/sec)	Wind Direction Medium	Wind Direction Range	Vertical Dispersion Coefficient[2] σz (m)
0	10/26/79	10:30A	180	30	805 (30)	7	72	0.8	7	50	4.8	NNE	240°-390°	1.7
1	10/31/79	1:30P	90	60	805	14	72	.7	4	0	2.1	SSE	50°-225°	2.5
2	11/01/79	10:30A	60	60	805	13	80	.7	5	20	1.6-3.0	SSE-S	80°-220°	2.3
3	11/01/79	2:00P	90	50	805	18	60	.7	5	60	4.4	S	120°-240°	2.0
4	11/02/79	11:00A	120	60	402 (15)	19	72	.7	6	100	4.8	S	130°-235°	1.7
5	6/14/80	12:00A	60	60	805	25	54	2.1	4	0	2.6	N	270°-470°	2.5
6	6/14/80	4:00P	60	60	805	28	46	2.1	4	0	3.0	N	245°-405°	2.3
7	6/18/80	12:00A	60	60	805	22	59	3.5	2	100	2.6	S	75°-280°	1.7
8	6/18/80	4:30P	45	60	805	24	59	3.5	2	10	2.9-1.6	SSW	105°-270°	2.5
9	6/19/80	11:15A	60	60	805	24	60	3.5	3	50	2.0	S	35°-290°	2.5

[1] Windspeed at 10 m elevation extrapolated from measurement at 1.5 m elevation.

[2] Estimated from D. Bruce Turner, Workbook fo Atmospheric Dispersion Estimates, AP-26, 1970.

TABLE A-2. SUMMARY OF ELECTRON MICROSCOPE ASBESTOS ANALYSIS

Test No.	Site No.	Air Sample Volume M^3	EM Fields Examined	SAED[1] Observations (fibers)					Asbestos Length >5μm (Fibers)	Total Asbestos Count (Fibers)	Mean Aspect Ratio	Estimated Mass of Counted Fibers (10^6μg)		
				Chrys.	Amphib.	Ambig.[2]	Non-Asbestos	No Pattern				Chrys.	Amphib.	Total Asbestos
1	1A	37	10	41	0	25	19	11	0	41	20	0.51	0	0.51
	1B	54	10	4	0	7	1	0	0	4	15	.04	0	.04
	2	31	10	13	2	25	21	5	0	15	18	.21	.05	.26
	3	33	10	15	0	19	35	6	0	15	22	.33	0	.33
	4	54	10	14	0	7	42	8	0	14	17	.15	0	.15
	5	33	10	10	2	3	5	3	0	12	17	.19	.10	.29
	6	51	10	2	2	3	4	0	0	4	8	.08	.29	.37
	7	46	10	2	2	6	12	6	0	4	20	.02	.21	.23
2	1A	29	6	24	5	19	12	6	3	29	18	36	12	48
	1B	36	10	2	0	2	2	0	0	2	39	.20	0	.20
	2	20	10	7	2	7	10	1	0	9	11	.09	.32	.41
	3	22	10	11	0	12	11	6	0	11	25	.12	0	.12
	4	36	10	16	2	9	11	4	0	18	18	.23	.22	.45
	5	22	10	8	0	2	6	4	0	8	15	.11	0	.11
	7	31	10	5	2	4	8	4	0	7	26	.07	.01	.08
3	1A	39	8	57	2	30	10	4	1	59	21	1.3	.045	1.34
	1B	51	10	4	0	3	1	0	0	4	14	.01	0	.01
	2	31	10	11	0	9	8	0	0	11	21	.10	0	.10
	3	33	10	9	0	4	16	1	0	9	16	.05	0	.05
	4	51	10	8	1	3	1	3	0	9	18	.09	.01	.10
	5	36	10	9	0	6	15	1	0	9	16	.06	0	.06
	6	51	10	14	1	9	10	2	0	15	17	.41	.03	.44
	7	46	10	10	0	4	8	2	0	10	21	.13	0	.13

[1] SAED = Selected Area Electron Diffraction

[2] Ambig. = Ambiguous; fibers not included in asbestos count.

TABLE A-2. (Continued)

Test No.	Site No.	Air Sample Volume M^3	EM Fields Examined	SAED[a] Observations (fibers)					Asbestos Length >5um (Fibers)	Total Asbestos Count (Fibers)	Mean Aspect Ratio	Estimated Mass of Counted Fibers (10^6 µg)		
				Chrys.	Amphib.	Ambig.	Non-Asbestos	No-Pattern				Chrys.	Amphib.	Total Asbestos
4	1A	58.	11	20	1	6	2	0	0	21	21	0.22	.028	.25
	6	68.	10	5	4	11	27	1	0	9	16	.04	.10	.14
	7	61.	10	8	0	4	10	1	1	8	14	.11	0.	.11
5	1A	17	2	47	0	58	5	1	0	47	20	1.1	0.	1.1
	1B	36	3	45	1	40	10	2	0	46	28	.8	.04	.8
	2	22	3	73	0	51	7	3	2	73	22	1.9	0	1.9
	3	24	8	41	0	41	19	2	0	41	21	.7	0	.7
	4	27	10	40	1	16	10	0	1	41	17	.3	.2	.5
	5	16	3	61	0	45	14	3	1	61	25	.9	0	.9
	6	24.	10	5	1	18	13	4	0	6	13	.1	.04	.14
7	1A	*	10	43	0	32	10	8	4	43	28	1.0	0.	1.0
	1B	*	5	44	0	52	6	1	0	44	23	1.2	0	1.2
	2	22.	3	56	1	40	6	3	1	57	20	1.1	.7	1.8
	3	24.	10	46	0	27	19	2	0	46	22	.7	0	.7
	4	27.	10	43	0	14	9	4	1	43	21	.3	0	.3
	6	22.	10	14	1	12	11	1	1	15	17	.12	.10	.22
	7	23.	10	9	0	25	25	4	0	9	13	.08	0.	.08

* Test 7, Site 1A and 1B sampled for only half of vehicular passes.

[a] SAED = Selected Area Electron Diffraction

TABLE A-3. ASBESTOS STRUCTURES IN ROAD EMISSION SAMPLES

Test No.	Site No.	EM Asbestos Structures									
		Chrysotile					Amphiboles				
		Fiber	Matrix	Bundle	Cluster	Σ	Fiber	Matrix	Bundle	Cluster	Σ
5	1A	19	27	1	0	47	0	0	0	0	0
	1B	15	27	3	0	45	1	0	0	0	1
	2	16	52	2	3	73	0	0	0	0	0
	3	14	25	0	0	39	0	0	0	0	0
	4	18	17	5	0	40	1	0	0	0	1
	5	25	34	1	1	61	0	0	0	0	0
	6	4	0	1	0	5	1	0	0	0	1
7	1A	26	14	3	0	43	0	0	0	0	0
	1B	16	26	2	0	44	0	0	0	0	0
	2	22	32	1	1	56	1	0	0	0	1
	3	27	19	0	0	46	0	0	0	0	0
	4	32	8	3	0	43	0	0	0	0	0
	6	-	-	-	-	14	1	0	0	0	1
	7	8	1	0	0	9	0	0	0	0	0
Distribution, %		44	51	4	1	100%					

APPENDIX B

FIELD TEST MEASUREMENTS CALCULATIONS

CALCULATIONS

Asbestos Emission Concentration

The fiber number count concentration was calculated from the following equation:

$$X_f = \frac{\Sigma \text{ Counts}}{\text{EM Fields}} \cdot \frac{\text{Filter Area}}{\text{Area per EM Field}} \cdot \frac{1}{\text{Air Volume}} \quad f/m^3 \qquad (1)$$

where

X_f = the fiber number count concentration, f/m^3

Count = the total number of fibers counted, f

EM Fields = the total number of EM grid openings examined

Filter Area = the total effective filter area used, cm^2

Area per EM Field = the area of each grid opening, cm^2

Air Volume = the product of flow rate x time, m^3

Concentration of Road Emissions

The fiber concentrations due to roadway emissions was determined as the difference between upwind and downwind concentrations, as follows:

$$X_{RD} = X_{Total} - X_{BKGD} \quad f/m^3 \qquad (2)$$

where

X_{RD} = the fiber concentration at the downwind station due to roadway emission

X_{Total} = the actual total count of fiber emissions, X_f at downwind station

X_{BKGD} = the actual total fiber number count concentration found at upwind station simultaneously with downwind air sampling

Fiber Mass Weight and Mass Concentration

The mass weight for each asbestos fiber is calculated by assuming the breadth measurement is the fiber diameter and the volume is the product of cross-section area and length. The density, σ, is taken to be 2.6 g/cm^3 for chrysotile and 3.0 g/cm^3 for amphibole. The mass concentration for each type of asbestos is then calculated as:

$$X_{mass} = [X_f] \cdot [\Sigma(\text{Fiber Volume})(\text{Density})]/[\Sigma \text{ Counts}] \quad g/m^3 \qquad (3)$$

Vehicular Traffic Source Strength Per Unit Distance

The source strength per unit distance q(f/m-sec), is calculated on the basis of concentration at a sampling site, χ (f/m^3), vertical dispersion standard deviation, σ_z, (m) (for a ground level receptor this depends on distance downwind from roadway and meteorological parameters (Turner, 1970)), and wind speed, μ (m/sec). For fiber emissions:

$$q_f = \frac{\sqrt{2\pi} \cdot X_f \cdot \sigma_z \cdot U}{2} \quad f/m\text{-sec} \qquad (4)$$

Vehicular Emission Factor

The vehicular emission factor, E, is the rate of emissions generated by one vehicular pass over a unit length of roadway. For fiber emissions:

$$E_f = 6 \times 10^4 \, q_f \cdot \frac{t}{N_v} \quad f/km\text{-vehicle} \qquad (5)$$

where

E_f = the emission factor for fiber count, f/km-vehicle

q_f = the fiber emission source strength per unit distance, f/m-vehicle

t = the total sampling time, min.

N_v = the total number of vehicular passes over time, t, vehicles

For mass emission factor, E_m:

$$E_m = E_f \cdot F \quad \text{g/km-vehicle} \qquad (6)$$

where

E_f = the fiber count emission factor, f/km-vehicle

F = the average mass of a single fiber, g/fiber

An estimate for the mass emission factor, E_m, of the test roadway control section was calculated with the above equation using field emission data. The following data was used:

$E_f = 370 \times 10^{10}$ fibers/km-vehicle

$F = 2 \times 10^{-14}$ g/fiber

$E_m = 0.074$ g/km-vehicle

Mass Emission Factor

The mass emission factor, E, can be calculated from an extension of the equation from AP-42 (Mann and Cowherd, 1978) for emission factor based on silt content.

$$E = (0.81 \times s\%) \left(\frac{U_v}{30}\right) \left(\frac{365-P}{365}\right) \left(\frac{W_f\%}{100}\right) \cdot (282) \quad \text{g/km-vehicle} \qquad (7)$$

where

$s\%$ = the silt content, which is weight percentage of aggregates on the road which can pass through a 200 mesh sieve (75 μm openings), %

U_v = the average vehicular speed, miles/hr

P = the annual number of days with >0.01 inches of rain

$W_f\%$ = the concentration of fibers in the roadway aggregate on a weight basis %

An estimate for the mass emission factor, E, of the test roadway control section was calculated with the above equation. The following data were used:

$P = 61 \times \frac{365}{245}$ annual days of rain

U_v = 30 mph vehicular speed

$s\%$ = 1.1% average silt content found on the road

$W_f\%$ = 1.0% average asbestos mass concentration in the -140 mesh fines from fresh quarry aggregates

$E = 2.1$ g/km-vehicle

APPENDIX C

EMISSION DISPERSION ESTIMATION

Concentrations downwind of a continuously emitting point source can be expressed by procedures used to make dispersion estimates by the Pasquill-Gifford method (Turner, 1970). For a ground level source with no plume rise, the concentrations can be expressed as:

$$X_p = \frac{Q}{\pi \sigma_y \sigma_z \cdot U} \qquad (1)$$

where

X_p = the concentration at a ground level receptor, downwind from a point source, f/m^3

Q = the ground level source emission rate, f/sec

σ_y = the horizontal standard deviation of plume concentration distribution, m

σ_z = the vertical standard deviation of plume concentration distribution, m

U = the mean wind speed, m/sec

The ratio, σ_y/σ_z, was calculated for values of σ_y and σ_z from 100 m to 400 m downwind from a ground level point source for stability classes B through D (Turner, 1970). The average ratio is:

$$\sigma_y/\sigma_z = 1.75$$

and its standard deviation is:

$$S = 0.062$$

The ratio is the same at the shorter distances for stability class A but falls off at 400 m to 1.3.

Substituting 1.75 σ_z for σ_y:

$$X_p = \frac{Q}{1.75 \pi \sigma_z^2 U} \qquad (2)$$

When the wind direction is normal to a ground level line source, concentrations downwind of a continuously emitting infinite ground level line source can be expressed (Turner, 1971) as:

$$\chi_L = \frac{2q}{\sqrt{2\pi} \cdot \sigma_z \cdot U} \qquad (3)$$

where

χ_L = the concentration at distance, x, downwind from the line source, f/m^3

q = the source strength per unit length, f/sec-m

σ_z = the vertical dispersion parameter, m

U = the wind speed, m/sec

Equations 2 and 3 can be used to relate the concentration ratio for two parallel receptors at distance, x, downwind from a line source to the concentration ratio of the same two receptors (at same meteorological conditions) at distance, x, directly downwind from two identical point sources.

From Equation 2:

$$\frac{\sigma_z\,(1)}{\sigma_z\,(2)} = \left[\frac{\chi_p\,(2)}{\chi_p\,(1)}\right]^{\frac{1}{2}} \qquad (4)$$

From Equation 3:

$$\frac{\sigma_z\,(1)}{\sigma_z\,(2)} = \frac{\chi_L\,(2)}{\chi_L\,(1)} \qquad (5)$$

So that:

$$\frac{\chi_L\,(2)}{\chi_L\,(1)} = \left[\frac{\chi_p\,(2)}{\chi_p\,(1)}\right]^{\frac{1}{2}} \qquad (6)$$

Equation 6 gives an estimate for $\chi_L(2)$ from $\chi_L(1)$ if the ratio $\chi_p(2)/\chi_p(1)$ is available. Note that the ratio between the two line source concentrations is less sensitive to local variations in the dispersion parameters than the ratio of the corresponding point source concentrations is.

Tracer measurements were made on two separate occasions to estimate terrain effects on atmospheric emission dispersion. With propane as a tracer,

a total hydrocarbon analyzer (Century Systems, Model DVA-118) was used to measure the concentrations of gas collected. Point source releases were made from the road at an elevation of 1.2 m. Bag samples at 1.2 m elevation were collected for a ten minute period at a distance of 20 m downwind from each road test section. Three collectors were placed, 7.5 m apart, in a line perpendicular to the mean wind direction.

Within the limits of the measurements, the concentration levels appear indistinguishable. Coefficients of variation, $S/\overline{X}$, of 0.11 and 0.08 were obtained for the peak line source concentration levels downwind from the five road test section. As a result, direct comparisons are believed to be valid between the emission from the control section and emission from the treated test section.

APPENDIX D

WIND TUNNEL FOR FUGITIVE EMISSIONS TESTING

A wind tunnel is an invaluable tool for testing fugitive emissions and measures for their control under a wide range of conditions. Test conditions can be repeatedly invoked and tested in a manner which cannot be matched in a natural setting. It is, however, the faithfulness with which the important stresses in nature are generated that the ultimate usefulness of the laboratory test rests.

With these considerations in mind, a wind tunnel was designed and constructed to test the effective applications of chemical controls for asbestos. Reduction in the scope of the study necessitated by reduction in funding did not permit the active use of the wind tunnel in the present program. The wind tunnel, as illustrated in Figure 3, was constructed in a closed cycle with a bank of HEPA (High Efficiency Particulate Air) filters to remove particulate matter from the recycled air. It is housed in a room under slightly negative pressures to prevent contamination of nearby areas. Simulated wind speeds of 0-20 m/sec (0-45 mph) can be generated in the test section. Wind speeds are controlled by pneumatically operated vector vanes on the blower intake. Also, manually operated vanes in the tunnel, immediately downstream of the blower, can be adjusted for further control. The test section is 0.6 m wide x 0.9 m high x 4.9 m long (2 ft x 3 ft x 16 ft) while the overall wind tunnel is 4.0 m wide x 17.1 m long x 1.8 m high (13 ft x 56 ft x 6 ft) not including filter housing which stands 2.4 m (8 ft) high.

The air movement is continuously directed throughout the wind tunnel. Adjustable vanes are positioned in the 90° turns to help balance the distribution of air in the windstream. In the final straight run before the test section, a honeycomb of plastic straws, each 0.58 cm (0.23 in.) diameter x 19.7 cm (7 3/4 inches) long, serves as a flow straightener to remove air turbulence. This is followed by a series of perforated plates to further balance out the air flow. Then just ahead of the test section, are located

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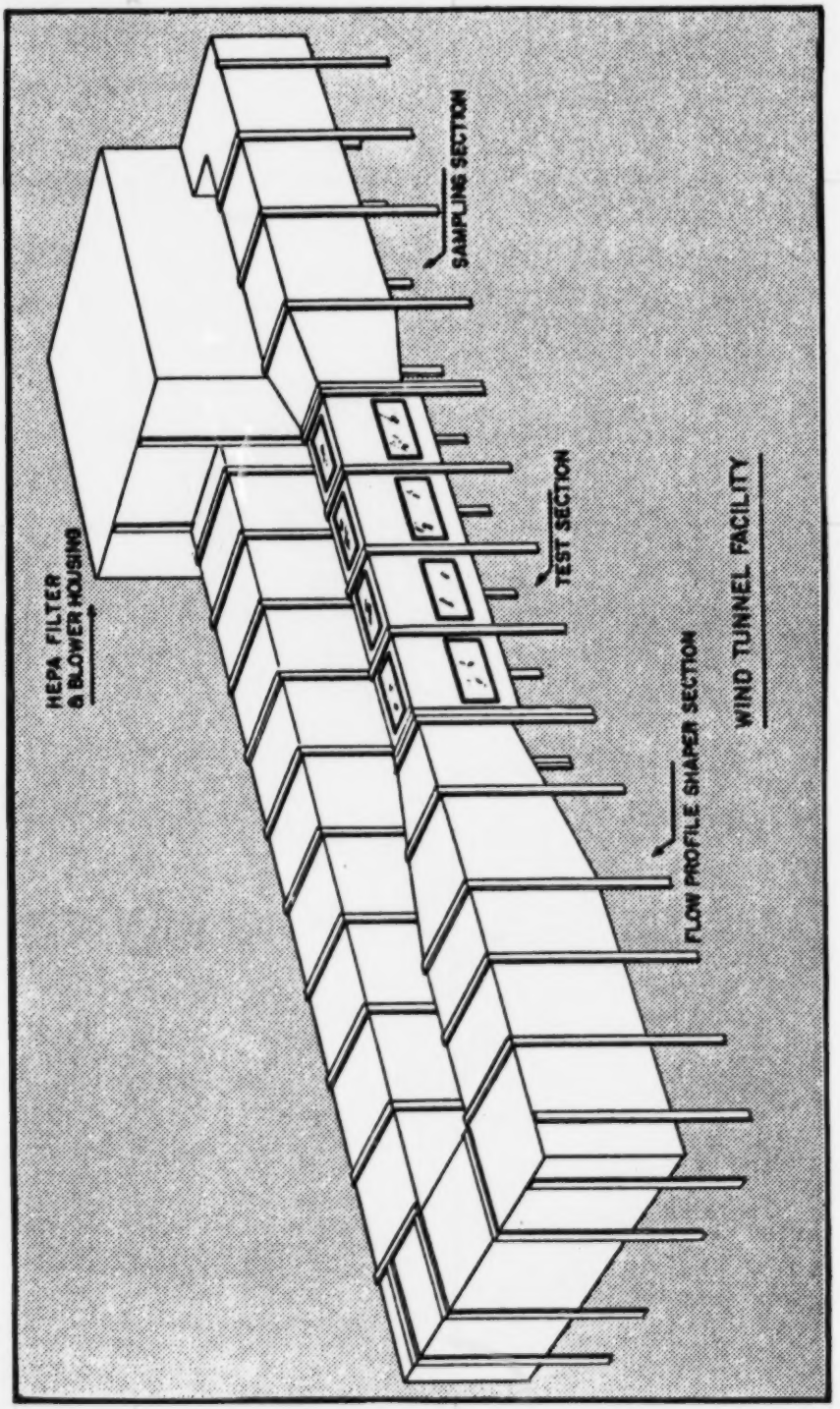

Figure 3. Wind Tunnel Facility.

short perforated plates in stepped heights which are positioned to create wind profiles and turbulence conditions to match those which might be met by open sources in urban or rural settings.

In the test section, the floor is recessed to accept thick test materials. Samples can be environmentally stressed (rain cycled, temperature cycled) elsewhere, and then placed in the wind tunnel for emission measurements. Currently, the wind tunnel is not regulated for temperature or humidity. At present, the temperature in the wind tunnel rises at the rate of 4°C/m (7.2°F/hr). For integrated emissions measurements, both temperature and humidity controls would be desirable.

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